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On-the-go soil mechanical strength measurement at different soil depths

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Abstract

Soil compaction limits root penetration below the plowing depth, reduces yields and makes plants more susceptible to drought stress. Applying uniform-depth tillage over the entire field to manage the soil compaction may be either too shallow or too deep and it can be costly. Variable-depth or site-specific tillage technology optimizes soil physical properties only where the tillage is needed by applying tillage at the required depth. Therefore, there is a need for a technology to determine the tillage depth based on soil mechanical strength at different depths of soil. Since soil cone penetrometers require a stop-and-go operation that can be time-consuming and costly, on-the-go measurement methods of soil mechanical strength have been investigated by some researchers. A measuring system with multiple instrumented shanks was designed and built to measure mechanical impedance of soil at different depths over the entire top 40 cm of the soil profile while moving through the soil. This system allows shanks for the simultaneous measurement of soil mechanical resistance at four depths, while moving through the field. The design allowed 10 cm of measurement depth per instrumented shank. Each instrumented shank consisted of an extended octagonal load cells. Each shank was calibrated in the lab by applying known forces and measuring output voltages. DT800 data logger (data Taker Co., UK) was used for data collection. Soil strength data was collected at 150 Hz. The instrumented measurement system was calibrated against cone penetrometer readings at same depth intervals by collecting intensive geo-referenced penetrometer data from a predetermined path and then running instrumented system with multiple shanks in the same path. The penetrometer data was averaged over 10 cm intervals and compared to the average force measurements from each instrumented shank of measurement system. There was a correlation with $R^2 = 0.77$ (the least correlation coefficient) at 0-10 cm depth and $R^2 = 0.83$ (the most correlation coefficient) at 30-40 cm depth between soil cone penetrometer data and instrumented measurement system values.

Key words: Site-specific tillage, precision farming, soil mechanical strength, penetrometer.

Introduction

Soil compaction is a significant problem in many soils of the world. In the most of these regions, hardpan restricts the root growth into deeper soil layers that are rich in terms of soil moisture and nutrients. This layer of soil usually has high penetration resistance and must be broken to penetrate roots into the subsoil. There have been a number of studies concentrated on finding the limiting soil strength values that prevent the root penetration and the plant growth [1, 11-14]. Consequently some of these researches focused on measurement of the strength of soil layers and its variation into the soil [5, 13-18].

Soil strength can be defined as the resistance of the soil to withstand the external forces without failure. Soil strength plays an important role in plant root growth. If the strength of the soil is too low, plants are unable to withstand the forces and because of the weak structure they cannot be anchored by the soil.

Measurement of soil strength has traditionally been conducted with the soil cone penetrometer. Upadhyaya *et al.* [17] indicated three types of penetrometers: a pointed device of a given mass that is allowed to fall a specific distance, a pointed device that is subjected to blows of a weight of given mass and a pointed device that is pushed into the soil (cone penetrometer). In agricultural operations, most frequently used type is the third type. Raper *et al.* [18] developed a multiple-probe soil cone for the purpose of measuring cone index values throughout the entire soil profile from trafficked middle across a crop row to untrafficked middle[18]. This machine has been successfully used in numerous studies. Multiple probe cone penetrometer mounted on the back of a tractor to automate the testing process and to allow for the averaging of five simultaneous measurements. Since soil cone penetrometers require a stop-and-go operation, some people studied on different methods that could be used on-the-go. Continuous measurement systems such as soil electrical conductivity appear to be promising alternative technologies [10-22]. Adamchuk *et al.* [2] developed a prototype vertical blade type soil resistance measurement system for mapping the spatial and vertical variation of soil mechanical resistance [2]. Manor and Clark developed an instrumented subsoiler shank for measuring soil resistance on-the-go to control the depth of the subsoiler shanks mounted on the same frame [15]. They placed three strain gauges on the subsoiler shank to measure the horizontal and vertical forces. Siefken *et al.* developed and tested a system for mapping soil mechanical resistance at three depths[20]. On-the-go instrumented systems referenced above have some limitation to use, such as, not precise measurement, measurement at single depth, soil disturbance, very hard to fabricate and/or potentially high manufacturing cost [9, 15, 20-21]. Therefore, a sensing system for on-the-go measurement of soil mechanical resistance at different soil depths without the main limitation mentioned above is needed.

Developing on-line variable-depth or site-specific tillage technology is the other objective of development of a reliable on-the-go measurement of soil mechanical resistance. Variable-depth or site-specific tillage technology optimizes soil physical properties only where the tillage is needed by applying tillage at the required depth [4]. Therefore, there is a need for a technology to determine the tillage depth based on soil mechanical strength at different depths of soil. The objectives of this research were to design and develop an instrumented multiple shanks able to measure continuously soil strength at different soil depths and also evaluating of this system at laboratory and field.

Materials and Methods

System developing: A measuring system with multiple instrumented shanks, shown in Fig. 1, was designed and built to measure mechanical impedance of soil at different depths over the entire top 40 cm of the soil profile while moving through the soil. The system consisted of four instrumented shanks which measure soil mechanical resistance at 0-10, 10-20, 20-30 and 30-40 cm of soil depths.

Soil mechanical resistance acts pressures to each sensing units, mounted on instrumented shanks, therefore extended octagonal load cell inside the sensing unit deforms and measures soil mechanical resistance at specified depth (Fig. 2). Load cells designed for the maximum soil strength of 8 MPa which obtained by examination of CI profile around Ardabil province and also based on other on-the-go measuring systems design basis [6-9]. Four strain gages attached to each octagonal load cell and were wired to a constant current Wheatstone bridge.

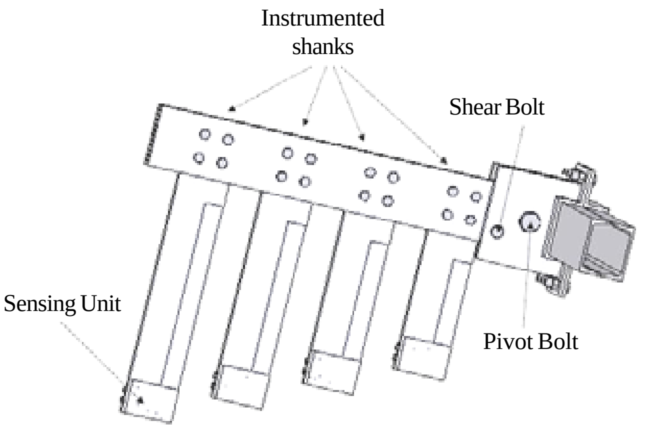

Figure 1. Soil mechanical resistance measuring system with multiple instrumented shanks.

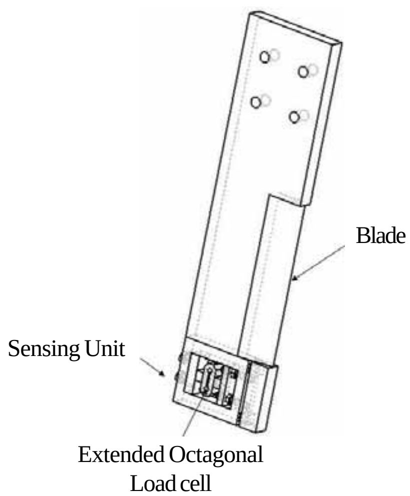

Figure 2. Schematics of instrumented shank and sensing unit.

The designed formulae of the extended octagonal transducers were originally based on analytical equations derived by Mclaughlin *et al.* [8, 16] reported by Chen *et al.* [8] for extended octagonal ring [8-16]. The sign convention employed in equations (1) and (2) is positive horizontal load, P_x compresses the ring; positive vertical load, P_y is upward; positive moment, M_0, is counter clockwise, and positive ring bending moment, M_ϕ tends to open or increase the radius of curvature of the rings. It should be mentioned in the instrumented system for measuring soil mechanical resistance P_y and M_ϕ are equal zero.

$$M_\phi = \frac{P_x r}{2}\left(\frac{2}{\pi} - \sin\phi\right) + \frac{P_y r}{2}\cos\phi - \frac{M_0\{(2+(\pi r/2L)) - ((2r/L)+\pi)\sin\phi\}}{8+(r\pi/L)+(2L\pi/r)}$$

for $0 < \phi \leq \pi$ (1)

$$M_\phi = \frac{P_x r}{2}\left(\frac{2}{\pi} + \sin\phi\right) - \frac{P_y r}{2}\cos\phi + \frac{M_0\{(2+(\pi r/2L)) - ((2r/L)+\pi)\sin\phi\}}{8+(r\pi/L)+(2L\pi/r)}$$

for $0 < \phi \leq 2\pi$ (2)

$$\varepsilon_\phi = \frac{6\,M_\phi}{E\,b\,t^2} \quad (3)$$

where r is the ring radius (measured to the ring neutral axis), t the ring thickness, b = 25 mm the ring width, $2L$ = 21.86 mm the distance between ring centers, ϕ is the angle measured from the x-axis with positive angles being counter clockwise (Fig. 3a-b).

DT-800 data logger (data Taker Co., UK) with CANgate GPS support was used for data collection. The data logger is equipped with 12-42 analog inputs and 16 digital channels. Soil strength data was collected at 150 Hz. Sensing resolution were selected 0.1 MPa to provide an acceptable signal to noise ratio.

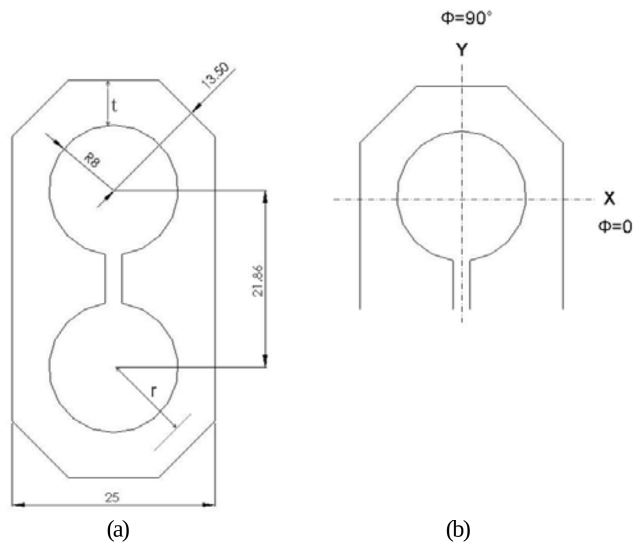

Figure 3. (a) Extended octagonal ring dimensions; (b) the face of octagonal ring showing coordinates and angles.

System calibration: Each sensing unit of instrumented shank in measuring system was calibrated in the lab by applying known forces and measuring output voltages. The calibration equation extracted indicates P_x in terms of output voltage. Then P_x is divided to cutting edge area to obtain soil strength at specified depth.

Field test: Field experiments were established at Faculty of Agriculture Research Farm, Ardabil, Iran (Latitude 38°21′N, Longitude 48°15′E) on sandy loam field. The instrumented shank was calibrated against hand pushed soil cone penetrometer readings at same depth intervals by collecting intensive georeferenced penetrometer data from a predetermined path and then running instrumented system with multiple shanks in the same path. The penetrometer data was averaged over 10 cm intervals and compared to the average force measurements from each shank of instrumented system.

Experiments consisted of six treatments arranged in randomized complete blocks with three replications. The treatments included two soil conditions (tilled or non-tilled), and two levels (9.8 and 13.5%) of soil moisture contents (% d.b.).

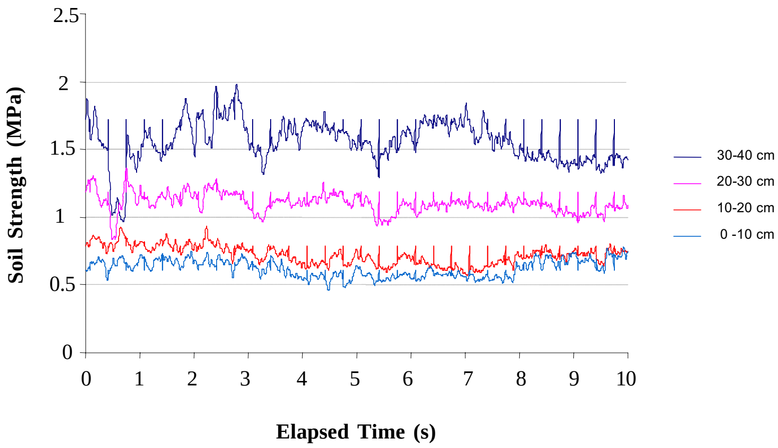

Figure 4. Horizontal soil strength data obtained from the measuring system on non-tilled plot.

Results and Discussion

Horizontal soil strength data obtained from all plots with instrumented measuring system over the entire top 40 cm of soil profile in each 10 cm soil depth. Fig. 4 shows an example of soil strength data measured on non-tilled plot at 0-10, 10-20, 20-30 and 30-40 cm of soil depths. The test field was planted in potato the previous year. The horizontal soil strength was calculated by dividing the total horizontal force from each 10 cm sensing unit by the area of the cutting wedge (25 cm^2).

In the most of experiment plots, soil strength data increased by an increase (10 cm) in soil depth. Cone index values also showed the same changes in the mentioned plots. As expected the soil strength values were significantly higher from the non-tilled compared to tilled plots. Also there was a strong positive correlation between horizontal soil strength values measured with the instrumented soil mechanical resistance measuring system and the hand pushed soil cone penetrometer data (Table 1). The measuring system achieved significantly lower measurement variance than a hand pushed soil cone penetrometer.

Increasing in soil moisture content resulted a decrease in horizontal soil mechanical strength. The same effects have been observed in soil cone index measurements in all plots. Statistical analysis of horizontal soil mechanical strength data and soil cone index values by using Proc ANOVA in SAS software clearly showed soil moisture content affected both horizontal soil mechanical strength and soil cone index in every soil conditions ($P<0.01$)[19].

Table 1. Correlation coefficients (%) between penetrometer data and the instrumented system with multiple shanks.

Penetrometer	Shank 0-10 cm	Shank 10-20 cm	Shank 20-30 cm	Shank 30-40 cm
0-10 cm	0.77	-	-	-
10-20 cm	-	0.78	-	-
20-30 cm	-	-	0.82	-
30-40 cm	-	-	-	0.83

Conclusions

The Horizontal Soil Mechanical Resistance Measurement System was developed and tested in both laboratory and field conditions. Field tests showed that the soil mechanical measuring system can be used to determine soil mechanical resistance at different depths of soil profile. The measurement system achieved significantly lower measurement variance than a hand pushed soil cone penetrometer. There was a correlation with $R^2 = 0.77$ and $R^2 = 0.83$ between soil cone penetrometer values and the horizontal soil mechanical resistance measurement system data at 0-10 and 30-40 cm soil depths respectively. Increasing in soil moisture content resulted in a decrease in horizontal soil mechanical strength values as well as soil cone index data.

Acknowledgements

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References

[1]Abbaspour-Gilandeh, Y., Alimardani, R., Khalilian, A., Keyhani, A.R. and Sadati, S.H. 2006. Energy requrement of site-specific and conventional tillage as affected by tractor speed and soil parameters. Int. J. Agri. Biol. **8**(4):499-503.

[2]Adamchuk, V. I., Morgan, M. T. and Sumali, H. 2001. Application of a strain gauge array to estimate soil impedance on-the-go. Trans. ASAE **44**(6):1377-1383.

[3]Alihamsyah, T., Humphries, E. G. and Bowers, C. G. 1990. A technique for horizontal measurement of soil mechanical impedance. Trans. ASAE **33**(1):73-77.

[4]Alimardani, R., Abbaspour-Gilandeh, Y., Khalilian, A., Keyhani, A.R. and Sadati, S.H. 2007. Energy savings with variable-depth tillage "a precision farming practice". American-Eurasian J. Agric. & Environ. Sci. **2**(4):442-447.

[5]Andrade, P., Rosa, U., Upadhyaya, S., Jenkins, B., Aguera, J. and Josiah, M. 2001. Soil Profile Force Measurements Using an Instrumented Tine. ASAE Paper No. 011060. ASAE, St. Joseph, Mich.

[6]ASAE Standards 2001b. ASAE S313.3: Soil Cone Penetrometer. American Society of Agricultural Engineers. St. Joseph, MI.

[7]ASAE Standards 2001a. ASAE D497.4: Agricultural Machinery Management Data. American Society of Agricultural Engineers. St. Joseph, MI.

[8]Chen, Y., McLaughlin, N.B. and Tessier, S. 2005. Double extended octagonal ring (DEOR) drawbar dynamometer. Soil Till. Res.

93(2):462-471.
[9]Chung, S. O., Sudduth, K. A. and Hummel, J. W. 2006. Design and validation of an on-the-go soil strength profile sensor. Trans. ASAE **49**(1):5-14.
[10]Ehrhardt, J. P., Grisso, R. D., Kocher, M. F., Jasa, P. J. and Schinstock, J. L. 2001. Using the Veris Electrical Conductivity Cart as a Draft Predictor. ASAE Paper No. 011012. ASAE, St. Joseph, Mich.
[11]Fulton, J.P., Wells, L.G., Shearer, S.A. and Barnhisel, R.I. 1996. Spatial Variation of Soil Physical Properties: A Precursor to Precision Tillage. ASAE Paper No.96-1012. ASAE, St. Joseph, Mich.
[12]Garner, T.H., Khalilian, A. and Sullivan, M.J. 1989. Deep tillage for cotton in coastal plain soils costs/returns. Proceedings, Beltwide Cotton Production Research Conferences, January 1989, Nashville, TN, pp. 168-171.
[13]Gorucu, S., Khalilian, A., Han, Y. J., Dodd, R. B., Wolak, F. J. and Keskin, M. 2001. Variable Depth Tillage Based on Geo-Referenced Soil Compaction Data in Costal Plain Region of South Carolina. ASAE Paper No.01-1016. ASAE, St. Joseph, Mich.
[14]Khalilian, A., Han, Y. J., Dodd, R. B., Sullivan, M. J., Gorucu, S. and Keskin, M. 2002. A Control System for Variable Depth Tillage. ASAE Paper No. 021209. ASAE, St. Joseph, Mich.
[15]Manor, G., and Clark, R. L. 2001. Development of an Instrumented Subsoiler to Map Soil Hard-Pans and Real-Time Control of Subsoiler Depth. ASAE Paper No. 011022. ASAE, St. Joseph, Mich.
[16]McLaughlin, N.B., Tessier, S. and Guilbert, A. 1998. Improved double extended octagonal ring drawbar transducer for 3D force measurement. Can. Agric. Eng. **40**:257-264.
[17]Upadhyaya, S.K., Chancellor, W.J., Perumpral, J.V., Schafer, R.L., Gill, W.R. and VandenBerg, G.E. 1994. Advances in Soil Dynamics. Vol.1. American Society of Agricultural Engineers.
[18]Raper, R.L. 1999. Site-specific tillage for site-specific compaction: Is there a need? Proceedings of the International Conference of Dryland Conservation/Zone Tillage, Beijing, China.
[19]SAS Institute Inc. 1999. SAS/STAT® User's Guide, Version 8, SAS Institute Inc., Cary, NC.
[20]Siefken, R.J., Adamchuk, V.I., Eisenhauer, D.E. and Bashford, L.L. 2005. Mapping soil mechanical resistance with a multiple blade system. Appl. Eng. Agric. **21**(1):15-23.
[21]Sirjacobs, D., Hanquet, B., Lebeau, B. and Destain, M. F. 2002. On-line soil mechanical resistance mapping and correlation with soil physical properties for precision agriculture. Soil Till. Res. **64**:231-242.
[22]Sudduth, K.S., Kitchen, N.R. and Drummond, S.T. 1998. Soil conductivity sensing on claypan soils: Comparison of electromagnetic induction and direct methods. Proc. 4th Intl. Conf. on Precision Agriculture, St. Paul, MN. ASA, CSSA, SSSA, Madison, WI, pp. 979-990.